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A SIMPLE CALIBRATION AND CHECKING FACILITY FOR FAST AND SLOW NEUTRON DETECTORS

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Research and Development Technical Report USNRDL-TR-302

28 January 1959

by

A. H. Redmond

U.S. NAVAL RADIOLOGICAL DEFENSE LABORATORY

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U N C L A S S I F I E D

A SIMPLE CALIBRATION AND CHECKING FACILITY FOR FAST AND SLOW NEUTRON DETECTORS

Research and Development Technical Report USNRDL-TR-302
NE 051-500

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Instrumentation

Technical Objective
AW-5a

Instruments Branch
K. F. Sinclair, Head

Nucleonics Division
A. Guthrie, Head

Scientific Director
P. C. Tompkins

Commanding Officer and Director
Captain J.H. McQuilkin, USN

U. S. NAVAL RADIOLOGICAL DEFENSE LABORATORY
San Francisco 24, California

U N C L A S S I F I E D

ABSTRACT

A simple facility is described for checking the sensitivity of doserate instruments for fast neutron detection, and for calibration of thermal neutron detectors. About 7 million plutonium-beryllium neutrons per second give a tolerance flux density of slow neutrons from the walls of a cavity in paraffin or water. Construction drawings of the cavity are given, and for the dimensions specified the constant is given for converting any plutonium-beryllium flux of neutrons to combined thermal and epithermal flux densities, so that instruments can be calibrated in standard flux densities.

The fast neutron doserate detectors use the same source, which has been shown to be equivalent to a polonium-beryllium source of the same strength, for a sensitivity check. A modified procedure using the source in the cavity is shown to give a somewhat lower flux of fast neutrons on the detector, but a rapid check can be made without setting up the source in air.

Measurements around the cavity with an additional insert of three-inch-thick paraffin surrounding the source-holding tube show that the doserate from fast neutrons around the cavity used for source storage is less than that around the original shipping container at comparable distances. The slow neutron flux density around the cavity during storage is negligible.

The fast and slow neutron instruments used in this development were the AN/PDR-47A and the AN/PDR-49.

SUMMARY

The Problem

BuShips Code 685C stated a need for a facility to check the sensitivity of the AN/PDR-47A, a fast neutron doserate reading instrument, and for calibration of the AN/PDR-49 an instrument sensitive to neutron density.

The Findings:

It has been shown possible to check the sensitivity of a fast neutron detector with plutonium beryllium neutrons (instead of the polonium-beryllium neutrons originally specified by an instrument manufacturer). A cavity in water or paraffin has been shown to give a flux density of slow and epithermal neutrons suitable for calibration of the AN/PDR-49 in terms of flux density, a more useful quantity than neutron density.

ADMINISTRATIVE INFORMATION

1. Background of Work

During FY 1957 and FY 1958, the U. S. Naval Radiological Defense Laboratory developed a device for measuring doserate from fast and slow neutrons. During FY 1959 emphasis has been placed upon developing the calibration procedure for slow neutrons.

2. Authorization and Funding

This work has been authorized by the Bureau of Ships under NE 051-500, Technical Objective AW-5a Radiac Program and included in the U. S. Naval Radiological Defense Laboratory FY 1959 Technical Program as Program B-5 Problem 5. Funds supporting this work were supplied by the Bureau of Ships on allotment 70178/59.

3. Description of Work

A cavity in water or paraffin was designed in which slow neutron detectors could be subjected to a tolerance flux of slow neutrons. The conversion of the source strength to slow neutron flux density was made experimentally, based upon earlier experiments conducted at the University of California.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

REPORT OF INVESTIGATION

INTRODUCTION

In connection with fission-reactor development and applications a need exists for a simple calibration facility for thermal neutron detectors, and for checking the response of fast neutron doserate instruments. As part of the work of developing such facilities for estimating slow neutron fluxes and doserates at naval shipyards, some study has been made for the Bureau of Ships Code 685C of the possibility of using a plutonium-beryllium neutron source as a standard source for both flux-sensitive instruments and doserate-sensitive instruments. Because of the long halflife of plutonium and relatively low cost, its use has seemed preferable to that of polonium.

The principal work described below is the development and tests of a slow neutron flux generator based on a generator developed at the University of California (UCRL 8359, W. Patterson, Roger Wallace, "A Method of Calibrating Slow Neutron Detectors"). It is shown that a tolerance flux density of slow neutrons results within a cubical cavity 15 inches on an edge with 4-inch-thick walls of water or paraffin wax when a plutonium-beryllium source emitting about 7 million neutrons per second is placed within the cavity according to a standard procedure. The principle on which the generator is based is that the fast neutrons from the source are slowed to near thermal velocities by scattering from the cavity walls. (Although the principal interest is in the slow flux, a primary fast flux is present at any point depending on the inverse square of the distance from the source.) The variation of slow neutron flux density over the walls of the cavity is unimportant for the calibration of thermal neutron detectors which follow a $1/v$ or $1/E$ response law (where v and E are the neutron velocity and energy), so that the detector is sensitive mainly to the slow neutron flux. As stated, the method provides a slow neutron flux density (instead of the neutron density only) so that a calibration for detectors placed within the cavity can be given either in terms of flux density of slow neutrons or, by simple conversion, in terms of doserate.

The entire calibration is based on a comparison of the responses of slow neutron detectors in the cavities in concrete, water and paraffin, taking the flux density in the concrete cavity determined at UCRL as a

standard figure.

Besides its use as a slow neutron flux generator, the cavity in paraffin is considered as a storage container for the plutonium-beryllium source. When an additional insert of paraffin is put into the cavity around the tube containing the source the doserates of fast neutrons are lower outside the cavity than outside the original cylindrical container with the source, as will be shown. The fluxes of slow neutrons around the modified cavity are shown to give a negligible doserate.

Following a brief description of the slow neutron flux generator, the basis for its use in calibration of slow neutron detectors is given in some detail. Since the slow neutron flux generator described uses a plutonium-beryllium source, it was desirable to check the response of the original cavity in concrete at UC to these neutrons; our entire calibration is based on the performance of the concrete cavity with polonium-beryllium neutrons. It is shown that the concrete cavity gives nearly the same flux per neutron with the two different sources; the results with a set of foils are also given.

The general problem of calibrating a doserate reading instrument has not been touched in the present work. Instead, a specific procedure is given for checking the sensitivity of an instrument following the manufacturer's direction, but with the substitution of a plutonium source of fast neutrons for the polonium-beryllium source specified for the interim fast neutron survey meter, the AN/PDR 47A. It is shown that the instrument sensitivity is the same with the two different sources of neutrons. Hence the longerlived plutonium source can be used for this check.

For some purposes a modified procedure which gives an approximate check of doserate sensitivity is suggested which makes unnecessary any handling of the source once a correlation has been established by a user of the facility. The comparison made is that between the doserate response of the fast neutron detector from a fast neutron source in air and from an aperture in a source container of paraffin.

THE SLOW NEUTRON FLUX GENERATOR

Figure 1 is a perspective view of the slow neutron flux generator showing the aluminum container for the four-inch-thick moderating material, either water or paraffin, and the top with the two holes for the source holder insert tube and for the detector cables. The cavity is used with

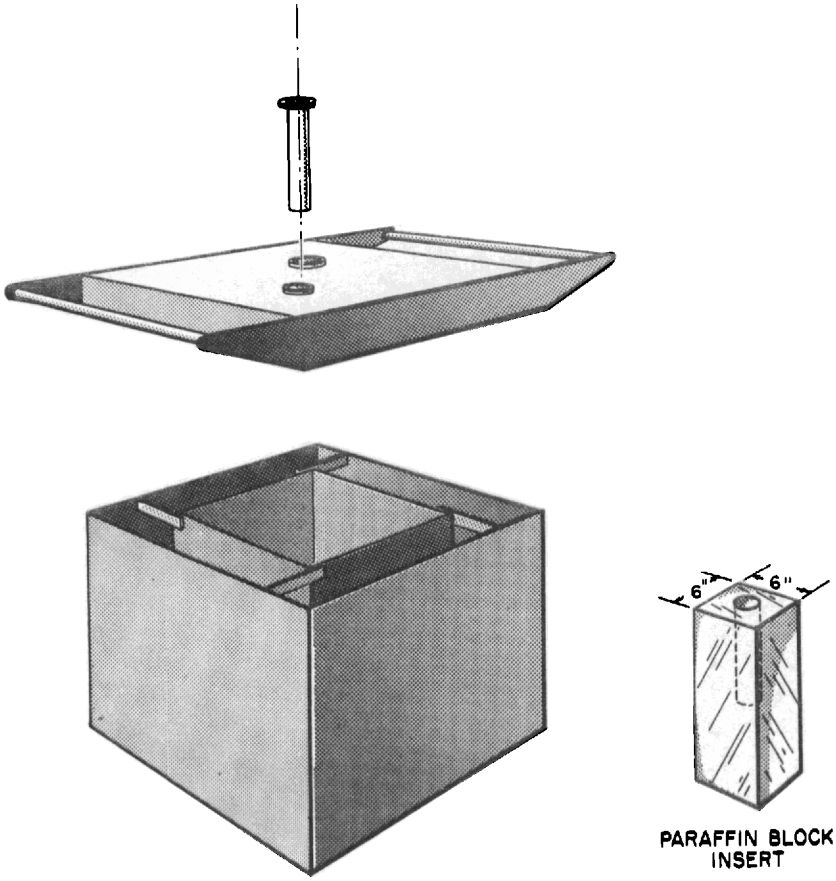

Fig. 1 Slow Neutron Flux Generator.

the source in the tube holder positioned halfway between the top and bottom walls and with the detectors lying on the cavity floor when a slow neutron flux of calculable magnitude is to be generated and the slow neutron detectors calibrated. The split block of paraffin on the right of the drawing when inserted into the cavity around the source holder tube adds an additional three inches of paraffin shielding when the generator is used for source storage, between measurement periods.

Cavity Constant With Walls of Water

The problem of determining the actual flux density provided by a given source of fast neutrons was undertaken by UCRL. A cavity in concrete, four feet on an edge with one foot thick walls was studied using indium foils. The flux density of slow neutrons was shown to be proportional to the fast neutron source strength and inversely proportional to the area of the surrounding concrete walls, as follows:

$$F = \frac{KS}{A}, \tag{1}$$

F being the flux density in neutrons per square centimeter per second S the source strength in neutrons per second and A the area of the cavity walls in square centimeters. The constant of proportionality K was determined to be 1.25 with a polonium beryllium source of neutrons.

In adapting the ideas studied to our needs with the smaller portable cavities it was necessary to evaluate the constant for scattering materials other than concrete. The simplest and most direct comparison was made, as follows: Our cavity, with walls of water, was used in parallel experiments with the cavity in concrete at UC with the same detectors, namely, borontrifluoride filled tubes, and the same sources of neutrons. By solving relation (1) for K, the ratio of the constants K' and K for the two cavities can be found as follows:

$$\frac{K_w}{K_c} = \frac{F'A'}{S'} \Big/ \frac{F\,A}{S} = \frac{F'A'}{F\,A} \tag{2}$$

The source strengths S' and S are equal, for they refer to the same source of neutrons, and cancel in the relation. Hence the cavity constants K_w (K_{water}) and K_c ($K_{concrete}$) are in the ratio of the detector readings multiplied by the ratio of areas of the two cavities. Evidently by using the ratio of the two flux densities denoted by F' and F, the

detectors need not be calibrated, since only a relative reading is needed. One precaution was taken, however, namely, to make the readings in the two cavities whose fluxes are being compared on the same scales of the instruments. Otherwise failure of the instrument scales to track could introduce an error into the ratio of the flux densities.

Four different instruments were available at different times with which to determine the ratio of flux densities in the water and concrete cavities. The result of determinations with two instruments using the plutonium source and with four instruments using the polonium source gave the ratio of constants for the two cavities as:

$$\frac{K_W}{K_C} = 1.35 \pm 0.05 \qquad \text{for plutonium beryllium neutrons.}$$

$$\frac{K_W}{K_C} = 1.22 \pm 0.03 \qquad \text{for polonium beryllium neutrons.}$$

Since the ratio of constants for the plutonium beryllium neutrons is of the greatest interest for the use intended, the former ratio is taken. Hence the constant for the cavity in water for the plutonium-beryllium source is computed as 1.25 x 1.35 = 1.7, since the comparison was based on the constant K_C for the source in concrete which had already been determined to be 1.25 by UCRL. The constant K_W then refers to the total flux of neutrons from the walls per emission rate of source neutrons. It shows that from the water walls an average of 1.7 neutrons emerged per source emitted, and hence indicates more than one trip per scattered neutron.

In the above table it is considered surprising that the constants for the two different kinds of cavities differed by as much as 10 percent with the two different neutron sources. Possibly placing the detectors and sources in slightly different relative positions, and errors in reading the instruments may account for the observed differences. But the differences seem real.

It has seemed worthwhile to try to compare the responses of the cavity in concrete to the plutonium and polonium sources with another detector. A set of measurements under well controlled conditions using indium foils as detectors with the plutonium and polonium sources were made. The results in the same cavity with the two sources, plutonium and polonium neutrons show that the relative flux with plutonium sources is slightly higher, as is also shown with the boron trifluoride detectors. The measurements with one set of 5 pairs of foils give the ratio of cavity constants as 1.065 ± 0.04, the flux being a few percent higher with plutonium neutrons. The subject is considered open; the difference with the two sources is not sufficient, it appears, to be very significant for the

determination of the standard flux density needed for the calibration facility, but will be checked with more foils and detectors as time allows.

Cavity Constant With Walls of Paraffin

After the direct comparison between the flux density with similar sources in cavities in concrete and water had been completed, BuShips Code 685C asked that a cavity using paraffin or polyethylene walls be studied and the constant evaluated. The cost of polyethylene appeard excessive so a bare wax cavity was made without the retaining aluminum walls. With conditions otherwise identical, a plutonium-beryllium neutron source emitting about 7 million neutrons per second was put into the source holder (as in Figure 1) and transferred from one cavity to the other with the detectors in the same relative positions in the two.

As in the earlier comparison with the detectors in the concrete and water cavities, the sources were the same, but here the wall areas were also the same. Hence the ratio of the detector readings in the two cavities gives the transfer factor for converting the constant in water to that in paraffin. For two different instruments in a number of trials the ratios of the fluxes were identical, namely, 1.28, the fluxes being higher in paraffin than in water. Basing the result on the figure 1.70 for K in the waterwalled cavity, the constant for the paraffin cavity is 2.1 .

A word about the conditions for calibrating detectors in the cavities: It had been observed in the rather large concrete cavity at UC that the relative positions of the sources and detectors did not greatly influence the results. In our smaller detectors it was possible to get about 20 percent larger apparent flux densities by putting the sources close to the detectors, indicating some fast-flux sensitivity in the detector. For this reason, after some trials it was decided to put the source into a standard position, namely, in the source holder tube, and insert it inside the top plate of the cavity so that the source itself was about halfway between the top and bottom walls. Moreover, some trials with the detectors in different positions showed little effect of distance beyond a certain minimum distance; nevertheless our measurements were made with the detectors lying on the bottom of the cavity, with their ends pointed away from the suspended source. In this position the fast-flux contribution was less than 5 percent of the total indication, as shown by a cadmium ratio of about 20 for the tubes in this position. The walls and front end of the detectors were covered with 40 mil thick cadmium for this measurement, but the detector end nearest the preamplifier could not be covered. Hence, the contribution of fast flux to the indication is considered to be less than 5 percent.

The Paraffin Cavity for Source Storage

The fast neutron dose at the surface of the paraffin cavity was measured on the side nearest the source in a horizontal plane through the cavity center, and in the center of the top wall. These measurements gave figures at the surface ranging from about 4 to 2 millirep per hour, or about 5 times tolerance; at 1 foot from the walls the doserates were about one-third to one-half those at the walls and not decreasing with the inverse square of distance.

The slow neutron flux densities, however, were low all around the paraffin cavity, amounting to at most about one-seventh of tolerance. Hence the slow neutron shielding is probably adequate, but more moderator around the source is needed to reduce the doserate from fast neutrons.

Referring again to Figure 1, the split paraffin block shown has a hole which allows the source container tube to fit into it, so that an effective 3 inches of additional paraffin shield is around the source when the generator is being used for storage. This additional moderator reduces the fast doserate to about half that without the paraffin insert when the measurement is made at the wall outside, and to half similarly at 1 foot. Figure 2 shows the measurements made at 1 foot in the indicated positions all around the paraffin walls. The whole numbers give the measured slow neutron flux density at the same positions. The fast neutron doserates are not falling off as the inverse square, but all rates shown on the drawing are below tolerance doserates at 1 foot. For comparison, the fast neutron doserate is shown around the wax filled drum used as shipping container and for source storage; no doserates around the cavity are larger than those around the shipping container and most are lower.

The measurements detailed above for calibration of the slow neutron detectors are of course to be made without the paraffin insert, for the detailed theory of computing the flux density is not available for this kind of cavity and source positioning. Nevertheless a reading with the instruments in the cavity with the insert in place showed that the flux density available in this unconventional arrangement was 80 percent of that without the insert. It is recommended that the calibration and the check with the detector outside the cavity not be carried out with the paraffin insert in place.

Design Details of the Slow Neutron Flux Generator

Figure 3 is a design drawing of the generator and accessories. The cost of fabricating the shell at a naval installation was about $200. If water is not used, the paraffin (density 0.931, containing about 2 percent of polyethylene) may be poured into the shell. When cast into

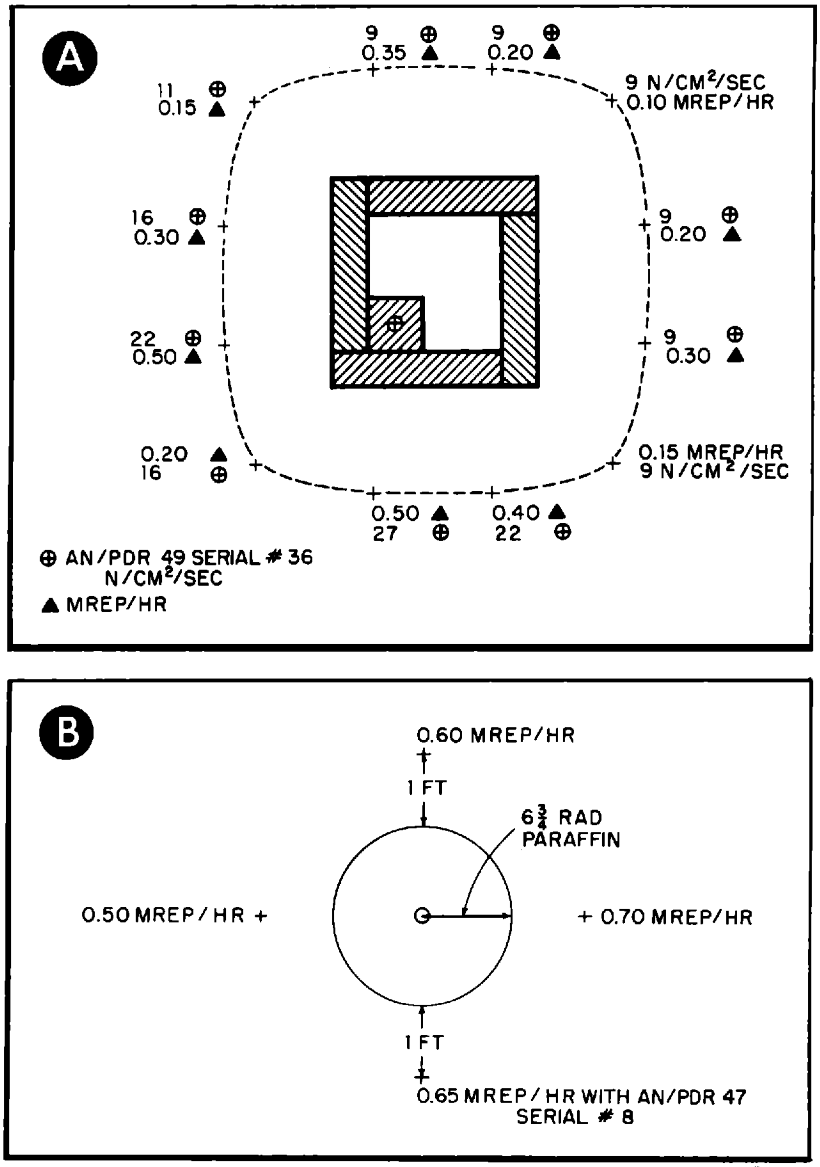

Fig. 2 Fast Neutron Dose Rates and Slow Neutron Flux Densities Around Paraffin Cavity Walls.

blocks about 4 x 20 x 20 inches, it cost about $15 per hundred pounds. If cast by a supplier, the price may be somewhat higher but probably will be less than $20 per hundred pounds. (It may be necessary to cast the bottom of the shell in two melts to keep shrinkage to a small figure). An item not shown in Figure 3 which may be of some value is a paraffin plug to be used in the source holder tube when the cavity is used for storage. The drawing of the cover was that for water; when paraffin is used the opening in the cover should be rather large, say 4 inches by 8 inches, and need only be covered to keep dust out.

SENSITIVITY OF A FAST NEUTRON DOSERATE READING INSTRUMENT TO PLUTONIUM-BERYLLIUM NEUTRONS

In converting a sensitivity to polonium beryllium neutrons to one for plutonium beryllium neutrons, two sources at UCRL were used with the AN/PDR-47A, the transistorized version of the former Raychronix El (Rudolf). Sensitivity, the response to unit flux density of neutrons, was computed for a number of positions of the counter with respect to both sources. One datum (in parentheses below), taken at two meters from the strong source of polonium beryllium neutrons, was left out of the average, owing to the possible influence of scattered neutrons in giving a spuriously high sensitivity. The other sensitivity data, taken with two instruments, are as follows: (Units are 10^{-2} millirep per hour per neutron per square cm per second.)

<u>For Polonium-Beryllium Neutrons</u>

Instrument No. 8				Avge	Instrument No. 35				Avge
(2.04)	1.72	1.62	1.72	1.69	(2.39)	1.79	1.83	1.70	1.77

<u>For Plutonium-Beryllium Neutrons</u>

Instrument No. 8			Avge	Instrument No. 35			Avge
1.64	1.58	1.86	1.69	1.64	1.83	1.70	1.69

It is felt from the closeness of the average responses of the instruments to the two sources that the sensitivities to the two sources are equal. Consequently, the plutonium-beryllium neutron sources recommended can be used in place of the polonium beryllium source specified in the

manual accompanying the two instruments, page 8, paragraph 5.4. The sensitivity figure for calibration remains, of course, the same; viz., $1.45 \pm 0.05 \times 10^{-2}$. (Evidently the detectors as received were not in calibration, but the relative responses only were being studied with the two sources here.)

Sensitivity Check with Source in Cavity

At the request of the Bureau of Ships, Code 685C, the possibility has been considered of using the source in place in the cavity in checking the fast neutron sensitivity of the interim AN/PDR-47A. Because the chamber of the 47A extends over three inches and radiators are present in the detector chamber, it is difficult to define a centroid for sensitivity checks. It is therefore desirable to keep the distance between the center of the source and the chamber sufficiently large that the "distance" measured between the chamber center and the source center is not too much in error from the uncertainty in distance. It has been convenient to keep this distance at 41 cms, center to center, while making the sensitivity check. The jig shown in Figure 3 fits over the source insert hole to keep the distance correct. Comparative measurements of doserate indication were therefore made at this distance with two instruments using the plutonium beryllium source (1) in air, (2) in the source holder with the detector above the source holder at the same distance, and (3) as in (2) but with the paraffin insert around the source holder. The two parallel tables give the results of these sensitivity checks under the circumstances:

Source to center of chamber distance 41 cms				% Reading in Air		
Inst. No.	Air	In Tube (mrep/hr)	With Insert	Air	In Tube	With Insert
8	4.3	3.8	3.7	100	88.4	86.0
35	6.0	5.0	3.0	100	83.3	66.0

Deviation of sensitivity in air from
correct figure as given by manufacturer

Inst. No. 8	13% low
" " 35	22% high

With so few data it is not useful to analyze the reasons for the large drop in apparent sensitivity with instrument No. 35 when the paraffin insert is put around the source holder tube. With an originally high sensitivity, with the discriminator set too low, the instrument is perhaps more susceptible to error from energy loss of neutrons. It appears, however, undesirable to use the insert in the cavity when making the

sensitivity check with the instrument. It seems little would be gained by making a hole in the cavity wall for this kind of sensitivity check, and the method used is considered the simplest likely to be found with the least interference with other functions of the slow neutron flux generator. It is recommended that a number of instruments be checked for their performance when held in the jig above the source in the standard position and a comparison be made with the same instruments in air for a more reliable correction factor to be given than this average of two data in the sixth column of the table for the source in the tube without the paraffin insert.

The performance capability of the AN/PDR-47A and the AN/PDR-49 is being evaluated by George Hitchcock who has made a number of the measurements reported here and made several valuable suggestions. Turner H. Bailey made the wax cavity and helped with the measurements. Samuel W. Lee contributed to the design and engineering of the aluminum shell.

DISCUSSION AND CONCLUSIONS

In connection with fission-reactor development and applications a need exists for a simple calibration facility for thermal neutron detectors, and for checking the response of fast neutron doserate instruments. Some study has been made of the possibility of using a standard source of plutonium beryllium neutrons for producing a standard flux of slow neutrons and for the sensitivity check needed.

The principal work described is the development and tests of a slow neutron flux generator based on a generator developed at the University of California Radiation Laboratory (UCRL 8359). The principle used is that of moderating the fast neutrons from the source by scattering within a cavity containing hydrogenous material so that a steady state flux density of slow neutrons results which depends on the source strength S, and the area of the cavity walls A, according to

$$F = \frac{KS}{A}$$

The determination of the constant K for a cavity in concrete was carried out by UCRL. The measurements made at NRDL were made in cavities of

water and paraffin, and the constants for these shown to be 1.70 and 2.1 . The constants refer to the particular size cavity made and described with working drawings in the report. A tolerance flux density of slow neutrons results when a source of about 7 x 10^6 neutrons per second is placed inside the cavity.

It is shown that the cavity in paraffin is suitable for source storage, the fast neutron doserate when an additional 3 inches of paraffin is placed around the source holder being of the order of tolerance at one foot from the walls, and the slow neutron flux density being negligible.

No fundamental work of calibrating the fast neutron doserate instrument has been done, but a sensitivity check has been shown possible with the source of fast neutrons used in the generator, and a modified method gives a check with the source inside the paraffin cavity.

Approved by:

A Guthrie

A. GUTHRIE
Head, Nucleonics Division

For the Scientific Director

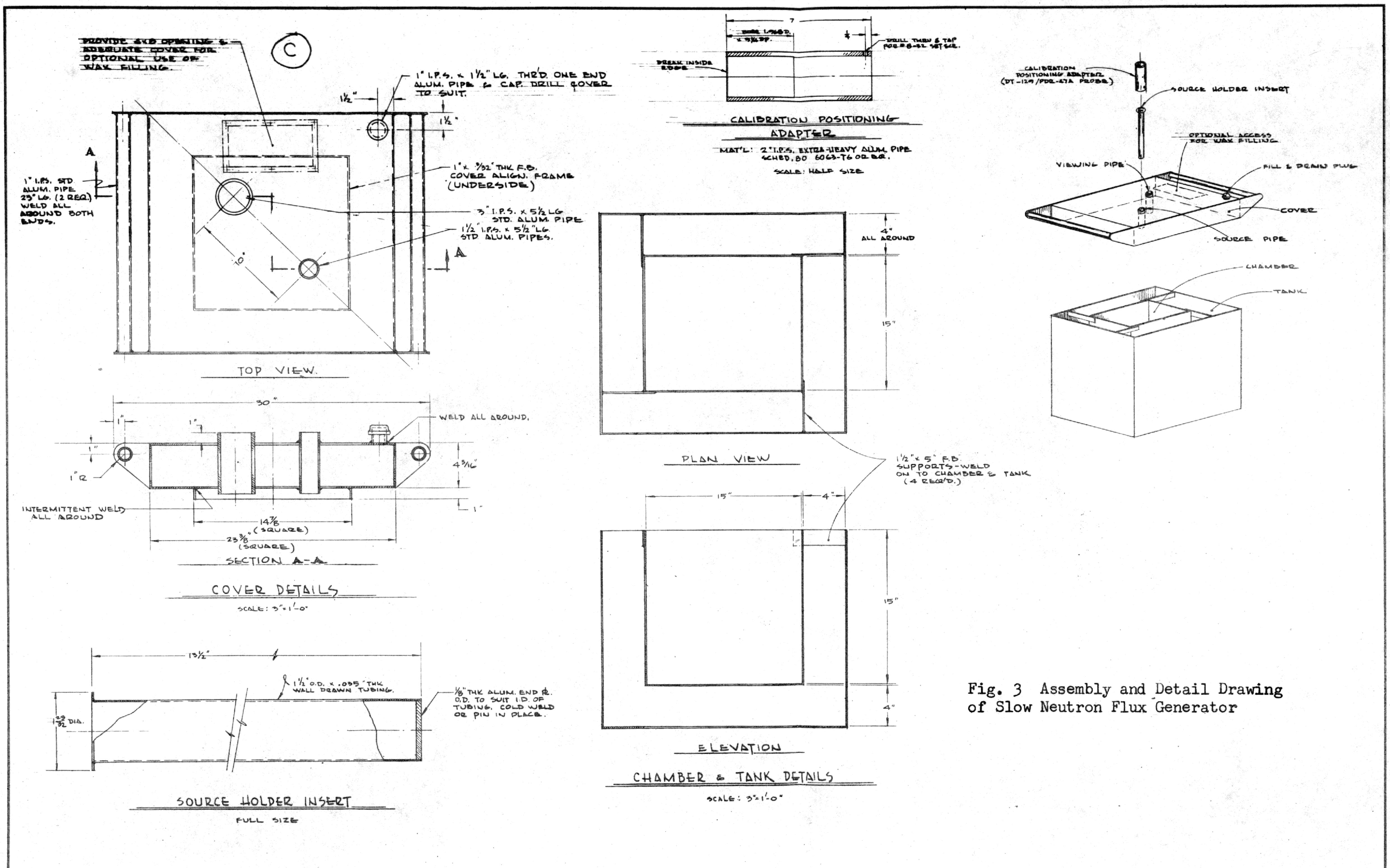

Fig. 3 Assembly and Detail Drawing of Slow Neutron Flux Generator

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122	Commander, FC/AFSWP, Sandia Base (FCDV)
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124	Assistant Secretary of Defense (Res. and Dev.)
125-129	Armed Services Technical Information Agency

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138	Argonne Cancer Research Hospital
139-148	Argonne National Laboratory
149	Atomic Bomb Casualty Commission
150-152	Atomic Energy Commission, Washington
153-155	Atomics International
156	Babcock and Wilcox Company
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159-162	Bettis Plant
163	Boeing Airplane Company, Seattle
164-167	Brookhaven National Laboratory
168	Bureau of Mines, Salt Lake City
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170	Chicago Operations Office
171	Chicago Patent Group
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177-178	Defence Research Member
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180	Division of Raw Materials, Denver
181	Division of Raw Materials, Grants Branch
182	Division of Raw Materials, Salt Lake City
183	Division of Raw Materials, Washington
184	Dow Chemical Company, Rocky Flats
185-188	duPont Company, Aiken
189	duPont Company, Wilmington
190	Edgerton, Germeshausen and Grier, Inc., Boston
191	Edgerton, Germeshausen and Grier, Inc., Las Vegas
192-193	General Electric Company (ANPD)
194-197	General Electric Company, Richland
198	General Nuclear Engineering Corporation
199	Gibbs and Cox, Inc.
200	Goodyear Atomic Corporation
201	Grand Junction Operations Office
202	Hawaii Marine Laboratory
203	Iowa State College
204-205	Knolls Atomic Power Laboratory
206-207	Lockheed Aircraft Corporation, Marietta
208-209	Los Alamos Scientific Laboratory
210	Lovelace Foundation
211	Mallinckrodt Chemical Works

212	Maritime Administration
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214	Mound Laboratory
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218	National Lead Company of Ohio
219	New Brunswick Area Office
220-221	New York Operations Office
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223	Nuclear Metals, Inc.
224	Oak Ridge Institute of Nuclear Studies
225	Patent Branch, Washington
226-229	Phillips Petroleum Company
230	Power Reactor Development Company
231-232	Pratt and Whitney Aircraft Division
233-234	Public Health Service, Washington
235	Public Health Service, Savannah
236-237	Sandia Corporation
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240-241	Union Carbide Nuclear Company (ORGDP)
242-246	Union Carbide Nuclear Company (ORNL)
247	Union Carbide Nuclear Company (Paducah Plant)
248	U.S. Geological Survey, Denver
249	U.S. Geological Survey, Menlo Park
250	U.S. Geological Survey, Naval Gun Factory
251	U.S. Geological Survey, Washington
252	U.S. Patent Office
253	UCLA Medical Research Laboratory
254	University of California, San Francisco
255-256	University of California Lawrence Radiation Lab., Berkeley
257-258	University of California Lawrence Radiation Lab., Livermore
259	University of Chicago Radiation Laboratory
260	University of Puerto Rico
261	University of Rochester (Technical Report Unit)
262	University of Rochester (Marshak)
263	University of Utah
264-265	University of Washington (Geballe)
266	University of Washington (Rohde)
267	Vitro Engineering Division
268	Western Reserve University
269	Westinghouse Electric Corporation (Schafer)
270	Yankee Atomic Electric Company
271-295	Technical Information Service, Oak Ridge

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296-325	USNRDL, Technical Information Division

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